FORM PTO-1390 U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE (REV 10-2000) **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C.371**		ATTORNEY'S DOCKET NUMBER **MCW-002US**
		U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 09/890694
INTERNATIONAL APPLICATION **PCT/GB00/00323**	INTERNATIONAL FILING DATE **07 February 2000 (07.02.00)**	PRIORITY DATE CLAIMED **05 February 1999 (05.02.99)**

TITLE OF INVENTION
OPTICAL WAVEGUIDE WITH MULTIPLE CORE LAYERS AND METHOD OF FABRICATION THEREOF

APPLICANT(S) FOR DO/EO/US
Paulo Vicente DA SILVA MARQUES et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C.371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This is an express request to promptly begin national examination procedures (35 U.S.C. 371(f)).
4. ☐ The US has been elected by the expiration of 19 months from the priority date (PCT Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ☐ is attached hereto (required only if not communicated by the International Bureau).
   b. ☒ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C 371(c)(2))
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). **(unexecuted) (4 Sheets);**
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98 **(2 sheets) with Form PTO-1449 (1 sheet);**
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included
13. ☒ A FIRST preliminary amendment **(7 sheets) (along with version of markings to show changes (5 sheets));**
    ☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information: **Transmittal Letter (2 sheets); PCT International Published Application (WO 00/46619) (with International Search Report) (38 sheets); International Preliminary Examination Report (18 sheets); Check in the amount of $1530.00 (Filing Fee) based on large entity; Certificate of First Class Mailing (1 sheet); and Return Postcard.**

JC17 Rec'd PCT/PTO 03 AUG 2001

U.S. APPLICATION NO. (if known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NO.
09/890694	PCT/GB00/00323	MCW-002US

17. ☒ The following fees are submitted:

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) .(a/o November 1, 2000):

Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1000**

International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO **$860**

International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.455(a)(2)) paid to USPTO **$710**

International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4)...........................**$690**

International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4)...................................**$100**

				CALCULATIONS	PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT =				$860.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☒ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				$130.00	
CLAIMS	**NUMBER FILED**	**NUMBER EXTRA**	**RATE**		
Total claims	**50**-20 =	**30**	X **$18.00**	$540.00	
Independent claims	**2**-3 =	**0**	X **$80.00**	$	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ **270.00**	$	
TOTAL OF ABOVE CALCULATIONS =				$1530.00	
☐ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by ½.				$	
SUBTOTAL =				$	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$	
TOTAL NATIONAL FEE =				$	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$	
TOTAL FEES ENCLOSED =				**$1530.00**	
				Amount to be: refunded	$
				charged	$

a. ☒ Checks in the amount of $ **1530.00** to cover the above fees are enclosed.

b. ☐ Please charge my Deposit Account No. ____________ in the amount of $______________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **12-0080**. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Anthony A. Laurentano, Esq.
LAHIVE & COCKFIELD, LLP
28 State Street
Boston, Massachusetts 02109
United States of America
(617)227-7400

Date: 03 August 2001

Anthony Laurentano

SIGNATURE

Anthony A. Laurentano

NAME

38,220

REGISTRATION NUMBER

09890694 .011002

JC09 Rec'd PCT/PTO 03 AUG 2001

09/890694

IN THE UNITED STATES PATENT DESIGNATED OFFICE (DO/US)
(National Phase of International App.: PCT/GB00/00323, W/O 00/46619)

In re the application of:
Paulo Vicente DA SILVA MARQUES et al.

International Application No.: **PCT/GB00/00323**

International Filing Date: **07 February 2000**

U.S. Serial No.: **Not Yet Assigned**

Filed: **Herewith**

For: **OPTICAL WAVEGUIDE WITH MULTIPLE CORE LAYERS AND METHOD OF FABRICATION THEREOF**

Attorney Docket No.: **MCW-002US**

BOX PCT
Commissioner for Patents
Washington, D.C. 20231

Certification Under 37 CFR 1.10

I hereby certify that the attached: Transmittal Letter (2 sheets); Preliminary Amendment (7 sheets (along with version of markings to show changes (5 sheets)); Unexecuted Declaration, Petition and Power of Attorney (4 sheets); PCT International Published Application (WO 00/46619) (with International Search Report) (38 sheets); International Preliminary Examination Report (18 sheets); Information Disclosure Statement (2 sheets); Form PTO-1449 (1 sheet); check in the amount of $1530.00 (Filing Fee) based on large entity; Certificate of Express Mailing (1 sheet); and Return Postcard are being deposited by me with the United States Postal Service "Express Mail Post Office to Addressee" service, Mailing Label No. **EL 916 825 478 US**, under 37 CFR 1.10 on the date indicated below and is addressed to the Box PCT, Commissioner for Patents, Washington, D.C. 20231.

Date: 03 August 2001

Name: Vinny Cardoso

Signature: Vinny Cardoso

JC17 Rec'd PCT/PTO 03 AUG 2001

09/890694

IN THE UNITED STATES PATENT DESIGNATED OFFICE (DO/US)
(National Phase of International App.: PCT/GB00/00323, W/O 00/46619)

In re the application of:
Paulo Vicente DA SILVA MARQUES et al.

International Application No.: **PCT/GB00/00323**

International Filing Date: **07 February 2000**

U.S. Serial No.: **Not Yet Assigned**

Filed: **Herewith**

For: **OPTICAL WAVEGUIDE WITH MULTIPLE CORE LAYERS AND METHOD OF FABRICATION THEREOF**

Attorney Docket No.: **MCW-002US**

BOX PCT
Commissioner for Patents
Washington, D.C. 20231

PRELIMINARY AMENDMENT

Dear Sir:

Preliminary to examination of the above-referenced patent application, please amend the enclosed above-titled International patent application as follows.

In the Claims

Please amend claims 4, 5, 8-11, 13, 14, 16, 17, 20-26, 28, 29, 33, 36, 39, 42, 50, 53, 55, 57, 58, 62, 65-67, 69-72, 77 and 78 as follows:

4. (Amended) A waveguide as claimed in claim 1, wherein the substrate comprises silicon and/or silica and/or sapphire.

5. (Amended) A waveguide as claimed in claim 1, wherein the substrate includes an intermediate layer-including a buffer layer formed on the substrate, wherein said buffer layer comprises a thermally oxidised layer of the substrate.

8. (Amended) A waveguide as claimed in Claim 5, wherein the intermediate layer further includes a lower cladding layer formed on said buffer layer.

9. (Amended) A waveguide as claimed in Claim 5, wherein the thickness of the buffer layer is in the range 5μm to 20μm.

10. (Amended) A waveguide as claimed in claim 1, wherein the second core layer is formed on the first core layer and said first core layer is formed on the substrate.

11. (Amended) A waveguide as claimed in Claim 1, wherein the first core layer is formed on the second core layer and said second core layer is formed on the substrate.

13. (Amended)A waveguide as claimed in claim 1, wherein the first core layer includes silica.

14. (Amended) A waveguide as claimed in claim 1, wherein the first core layer dopant includes dopant ions, including tin and/or cerium and/or sodium.

16. (Amended) A waveguide as claimed in claim 1, wherein the second core layer includes silica.

17. (Amended) A waveguide as claimed in claim 1, wherein the second core layer includes a phosphorus oxide.

20. (Amended) A waveguide as claimed in Claim 16, wherein the second core layer dopant includes a rare earth and/or a heavy metal and/or compounds of these elements.

21. (Amended) A waveguide as claimed in Claim 16 wherein the second core layer dopant includes rare earth is Erbium or Neodymium.

22. (Amended) A waveguide as claimed in claim 1, wherein the refractive indices of the first core layer and the second core layer are substantially equal.

23. (Amended) A waveguide as claimed in claim 1, wherein the refractive index of the waveguide core differs from that of the substrate by at least 0.05%.

24. (Amended) A waveguide as claimed in claim 1, wherein the thickness of the first core layer is in the range 0.2μm to 30μm.

25. (Amended) A waveguide as claimed in claim 1, wherein the thickness of the second core layer is in the range 0.2μm to 30μm.

26. (Amended) A waveguide as claimed in Claim 24, wherein the width of the waveguide core lies in the range 0.4μm to 60μm.

28. (Amended) A waveguide as claimed in claim 1, wherein the refractive index of the substrate and the refractive index of the upper cladding layer are substantially equal.

29. (Amended) An optical waveguide according to Claim 1, wherein the first core layer includes at least 17% wt germanium dopant.

33. (Amended) A method as claimed in Claim 30, wherein the formation of the substrate includes the formation of an intermediate layer formed on said substrate including the formation of a buffer layer which is formed by thermally oxidising the substrate.

36. (Amended) A method as claimed in Claim 33, wherein the formation of the intermediate layer further includes the formation of a lower cladding layer formed on said buffer layer.

39. (Amended)A method as claimed in Claim 30, wherein the second core layer is formed on the first core layer and wherein the first core layer is formed on the substrate, and wherein a further first core layer is formed on the second core layer such that the first core layer sandwiches the second core layer.

42. (Amended) A method as claimed in Claim 30, wherein the steps of forming any one of the substrate, first core layer, the second core layer, and the upper cladding layer comprise the steps of: depositing each layer; and

at least partially consolidating each layer.

50. (Amended) A method as claimed in Claim 30, wherein the concentration of the first core layer dopant is selectively controlled during the formation of the first core layer and the concentration of the second core layer dopant is selectively controlled during the formation of the second core layer so that the refractive index of the first core layer and the refractive index of the second core layer are substantially equal.

53. (Amended) A method as claimed in Claim 42,wherein at least one of the substrate, the first core layer, the second core layer, and the upper cladding layer is deposited by a Flame Hydrolysis Deposition process and/or Chemical Vapour Deposition process.

55. (Amended) A method as claimed in Claim 42, wherein the consolidation is by fusing using a Flame Hydrolysis Deposition burner.

57. (Amended) A method as claimed in Claim 54, wherein the step of fusing the lower cladding layer and the step of fusing the first core layer and/or the second core layer are performed simultaneously.

58. (Amended) A method as claimed in Claims 30, wherein the waveguide core is formed from the first core layer and the second core layer using a dry etching technique and/or a photolithographic technique and/or a mechanical sawing process.

62. (Amended) A laser waveguide with multiple core layers for transmitting an optical signal, the laser waveguide comprising a waveguide as claimed in claim 1, the laser waveguide further comprising:

at least one grating formed in said waveguide core.

65. (Amended) A laser waveguide as claimed in Claim 63, wherein the interference mirror is butt-coupled to or directly deposited at the input of the waveguide.

66. (Amended) A laser waveguide as claimed in Claim 62, wherein the laser waveguide includes two mirrors and a grating.

67. (Amended) A laser waveguide as claimed in Claim 62, wherein the laser waveguide includes one mirror and two gratings.

69. (Amended) A laser waveguide as claimed in Claim 62, wherein the grating formed is a Bragg grating.

70. (Amended) A laser waveguide as claimed in Claim 62, wherein said grating forms an output coupler for said laser waveguide.

71. (Amended) A laser waveguide as claimed in Claim 62, further comprising an optical interference mirror butt coupled to or directly deposited at the output of the waveguide.

72. (Amended) A method of fabricating a laser waveguide, comprising forming a waveguide according to a method as claimed in Claim 30, the method of fabricating the laser waveguide further including the steps of:

forming at least one grating in said waveguide core, wherein the grating is formed using a laser operating at a wavelength in the range of 150 nm to 400 nm through a phase mask deposited on top of said upper cladding layer of the waveguide.

77. (Amended) A method as claimed in Claims 72, wherein the grating is formed using a using an interference side writing technique.

78. (Amended) A method as claimed in Claim 72, wherein the grating is formed using a direct writing technique.

Please cancel claims 6, 7, 15, 18, 19, 27, 34, 35, 37, 38, 40, 41, 44-49, 52, 56, 60, 61, 64, 68, 73-76, 79-85.

REMARKS

Applicants amend the claims to remove multiple dependencies, to provide proper antecedent basis, and to address other matters of form. The foregoing amendments introduce no new matter and are not related to issues of patentability.

Entry of the foregoing Preliminary Amendment is respectfully in order and requested.

If there are any questions regarding the amendments to the application, we invite the Examiner to call Applicant's representative at the telephone number below.

Respectfully submitted,

LAHIVE & COCKFIELD, LLP

Anthony A. Laurentano
Registration No. 38,220
Attorney for Applicants

28 State Street
Boston, MA 02109
(617) 227-7400

Date: **August 3, 2001**

Version With Markings To Show Changes Made

Please amend claims 4, 5, 8-11, 13, 14, 16, 17, 20-26, 28, 29, 33, 36, 39, 42, 50, 53, 55, 57, 58, 62, 65-67, 69-72, 77 and 78 as follows:

4. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the substrate comprises silicon and/or silica and/or sapphire.

5. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the substrate includes an intermediate layer~~.~~, including a buffer layer formed on the substrate, wherein said buffer layer comprises a thermally oxidised layer of the substrate.

8. A waveguide as claimed in Claim ~~6 or Claim 7~~ 5, wherein the intermediate layer further includes a lower cladding layer formed on said buffer layer.

9. A waveguide as claimed in ~~any of~~ Claim~~s~~ ~~6 to 8~~ 5, wherein the thickness of the buffer layer is in the range ~~5m~~ 5μm to ~~20m~~ 20μm.

10. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the second core layer is formed on the first core layer and said first core layer is formed on the substrate.

11. A waveguide as claimed in ~~any of~~ Claim~~s~~ 1 ~~to 9~~, wherein the first core layer is formed on the second core layer and said second core layer is formed on the substrate.

13. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the first core layer includes silica.

14. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the first core layer dopant includes dopant ions~~.~~, including tin and/or cerium and/or sodium.

16. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the second core layer includes silica.

17. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the second core layer includes a phosphorus oxide.

20. A waveguide as claimed in ~~any of~~ Claims 16 ~~to 19~~, wherein the second core layer dopant includes a rare earth and/or a heavy metal and/or compounds of these elements.

21. A waveguide as claimed in Claim ~~20~~ 16, wherein the second core layer dopant includes ~~rare earth is~~ Erbium or Neodymium.

22. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the refractive indices of the first core layer and the second core layer are substantially equal.

23. 18. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the refractive index of the waveguide core differs from that of the substrate by at least 0.05%.

24. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the thickness of the first core layer is in the range ~~0.2m~~ 0.2μm to ~~30m~~ 30μm.

25. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the thickness of the second core layer is in the range ~~0.2m~~ 0.2μm to ~~30m~~ 30μm.

26. A waveguide as claimed in Claim ~~24~~,19 wherein the width of the waveguide core lies in the range ~~0.4m~~ 0.4μm to ~~60m~~ 60μm.

28. A waveguide as claimed in ~~any preceding~~ claim 1, wherein the refractive index of the substrate and the refractive index of the upper cladding layer are substantially equal.

29. An optical waveguide according to ~~any of~~ Claims 1 ~~to 28~~, wherein the first core layer includes at least 17% wt germanium dopant.

33. A method as claimed in ~~any of~~ Claims 30 ~~to 32~~, wherein the formation of the substrate includes the formation of an intermediate layer formed on said substrate including the formation of a buffer layer which is formed by thermally oxidising the substrate.

36. A method as claimed in Claim ~~34 or Claim 35~~ 33, wherein the formation of the intermediate layer further includes the formation of a lower cladding layer formed on said buffer layer.

39. A method as claimed in ~~any of~~ Claims 30 ~~to 38~~, wherein the second core layer is formed on the first core layer and wherein the first core layer is formed on the substrate~~.~~, and wherein a further first core layer is formed on the second core layer such that the first core layer sandwiches the second core layer.

42. A method as claimed in ~~any of~~ Claims 30 ~~to 41~~, wherein the steps of forming any one of the substrate, first core layer, the second core layer, and the upper cladding layer comprise the steps of: depositing each layer; and

at least partially consolidating each layer.

50. A method as claimed in ~~any of~~ Claims 30 ~~to 49~~, wherein the concentration of the first core layer dopant is selectively controlled during the formation of the first core layer and the concentration of the second core layer dopant is selectively controlled during the formation of the second core layer so that the refractive index of the first core layer and the refractive index of the second core layer are substantially equal.

53. A method as claimed in ~~any of~~ Claims 42 ~~to 52~~, wherein at least one of the substrate, the first core layer, the second core layer, and the upper cladding layer is deposited by a Flame Hydrolysis Deposition process and/or Chemical Vapour Deposition process.

55. A method as claimed in ~~any of~~ Claim~~s~~ 42~~ to 54~~, wherein the consolidation is by fusing using a Flame Hydrolysis Deposition burner.

57. A method as claimed in Claim ~~55 or Claim 56~~ 54, wherein the step of fusing the lower cladding layer and the step of fusing the first core layer and/or the second core layer are performed simultaneously.

58. A method as claimed in ~~any of~~ Claim~~s~~ 30~~ to 57~~, wherein the waveguide core is formed from the first core layer and the second core layer using a dry etching technique and/or a photolithographic technique and/or a mechanical sawing process.

62. A laser waveguide with multiple core layers for transmitting an optical signal, the laser waveguide comprising a waveguide as claimed in ~~any of~~ claim~~s~~ 1 ~~to 29~~, the laser waveguide further comprising:

at least one grating formed in said waveguide core.

65. A laser waveguide as claimed in Claim 63~~-64~~, wherein the interference mirror is butt-coupled to or directly deposited at the input of the waveguide.

66. A laser waveguide as claimed in ~~any of~~ Claim~~s~~ 62~~ to 65~~, wherein the laser waveguide includes two mirrors and a grating.

67. A laser waveguide as claimed in ~~any of~~ Claim~~s~~ 62~~ to 65~~, wherein the laser waveguide includes one mirror and two gratings.

69. A laser waveguide as claimed in ~~any of~~ Claim~~s~~ 62~~ to 68~~,wherein the grating formed is a Bragg grating.

70. A laser waveguide as claimed in ~~any of~~ Claim~~s~~ 62~~ to 69~~, wherein said grating forms an output coupler for said laser waveguide.

71. A laser waveguide as claimed in ~~any of~~ Claim~~s~~ 62~~ to 70~~, further comprising an optical interference mirror butt coupled to or directly deposited at the output of the waveguide.

72. A method of fabricating a laser waveguide, comprising forming a waveguide according to a method as claimed in ~~any of~~ Claim~~s~~ 30 ~~to 61~~, the method of fabricating the laser waveguide further including the steps of:

forming at least one grating in said waveguide core~~.~~,wherein the grating is formed using a laser operating at a wavelength in the range of 150 nm to 400 nm through a phase mask deposited on top of said upper cladding layer of the waveguide.

77. A method as claimed in ~~any of~~ Claim~~s~~ 72 ~~to 74~~, wherein the grating is formed using a using an interference side writing technique.

78. A method as claimed in ~~any of~~ Claim~~s~~ 72 ~~to 74~~, wherein the grating is formed using a direct writing technique.

Please cancel claims 6, 7, 15, 18, 19, 27, 34, 35, 37, 38, 40, 41, 44-49, 52, 56, 60, 61, 64, 68, 73-76, 79-85.

Rec'd PCT/PTO 03 AUG 2001
09/890694

OPTICAL WAVEGUIDE WITH MULTIPLE CORE LAYERS AND METHOD OF FABRICATION THEREOF

FIELD OF THE INVENTION

This invention relates to an optical waveguide with multiple core layers and a method of fabrication thereof.

In particular, the invention relates to a doped planar waveguide with multiple core layers and which includes both active and passive components and to a method of fabricating a planar waveguide for an optical circuit in which the core is composed of layers of different materials.

BACKGROUND OF THE INVENTION

Planar waveguides can be passive devices or can include active components; for example, modulators, couplers, and switches. Planar waveguides incorporating active components are extremely advantageous as they can be used to provide integrated

optic packages which can serve as complete transmitting modules with, for example, components for amplitude or phase modulation, or multiplexing in an optical communication network.

Rare earth doped fibre amplifiers, for example erbium or neodymium doped fibre amplifiers, are known to have several advantages in optical communication networks such as high gain, low noise, high power conversion efficiency and wide spectral bandwidth. The present invention seeks to provide the same advantages in planar rare earth doped waveguides and moreover to provide a laser waveguide amplifier which can be used, for example, in an optical communication network to amplify attenuated signals.

Planar waveguide technology is important in the fabrication of lasers and optical amplifiers due to the superior stability, compact geometry of planar waveguide technology. Also, active components, for example modulators, can be integrated into the planar device.

A variety of techniques, including flame hydrolysis deposition (FHD), sputtering, plasma enhanced chemical vapour deposition (CVD) and ion-exchange can be used in the fabrication of silica-based planar waveguides doped with rare-earth ions and which display laser characteristics.

In such laser amplifying waveguides, it is desirable to obtain a high concentration of rare earth ions in order to achieve very compact and efficient devices.
However, high concentrations of rare earth ions in a waveguide layer with relatively low solubility can result in the formation of clusters of rare earth ions.

The interaction between the rare earth ions in such clusters quenches the excited state required for the lasing process and thus degrades the optical amplification provided by the waveguide.

Other complications arise in the fabrication of laser waveguides for applications which require single mode transmission, narrow spectral bandwidths, and/or precise control of the lasing wavelength depend critically on their cavity type. Laser waveguides which have butt-coupled mirrors on the waveguide ends or dielectric reflection mirrors are known in the art but suffer to a greater or lesser degree from certain disadvantages; for example, low spectral selectivity.

Bragg gratings incorporated in a waveguide core can provide enhanced spectral selectivity. The fabrication of such gratings is affected by the host glass composition present in the waveguide core which determine the UV absorption band of the core material and thus its photosensitive properties. For example, if phosphorus is used as a core dopant ion it can alleviate the formation of rare earth ion clusters but has the disadvantage that it reduces the amount of absorption in the UV and thus reduces the photosensitivity of the core. If germanium is used as a core dopant ion it can increase the photosensitivity of the core but has the disadvantage of promoting rare earth cluster formation.

The introduction of a Bragg grating can be effected in a planar waveguide by a number of known methods which suffer to a greater or lesser degree from certain disadvantages. The invention provides an optical waveguide with multiple core layers which is suitable for forming a laser waveguide with a high degree of

spectral selectivity. The waveguide core combines two different types of silica based layers and these core layers obviate or mitigate the aforementioned disadvantages which arise when seeking to fabricate an in-core Bragg grating to enhance the spectral selectivity of the laser waveguide. The waveguide formed enables in-core Bragg grating formation at a range of UV wavelengths above 150 nm.

<u>SUMMARY OF THE INVENTION</u>

In accordance with a first aspect of the invention there is provided an optical waveguide with multiple core layers comprising: a substrate; a waveguide core formed on said substrate; and an upper cladding layer embedding said waveguide core; wherein said waveguide core comprises a first core layer and a second core layer.

Preferably, the substrate comprises silicon and/or silica and/or sapphire.

Preferably, the substrate includes an intermediate layer. The intermediate layer may include a buffer layer formed on the substrate. The buffer layer may comprise a thermally oxidised layer of the substrate.

The intermediate layer may further include a lower cladding layer formed on said buffer layer.

Preferably, the thickness of the buffer layer is in the range 5 μm to 20 μm.

The second core layer may be formed on the first core layer and said first core layer may be formed on the substrate. Alternatively, the first core layer may be

formed on the second core layer and said second core layer may be formed on the substrate. A further first core layer may be formed on the second core layer such that the first core layer sandwiches the second core layer.

Preferably, the first core layer includes a dopant to permit the first core layer to exhibit a photosensitive response. The first core layer may include silica.

Preferably, the first core layer includes a germanium oxide and/or a boron oxide. The first core layer dopant may include dopant ions. Preferably, the first core layer dopant ions include tin and/or cerium and/or sodium.

The second core layer may include a dopant to induce amplification of an optical signal transmitted through said waveguide core. The second core layer may include silica. The second core layer may include a phosphorus oxide. The second core layer dopants may include dopant ions. The second core layer dopant may include a mobile dopant.

Preferably, the second core layer dopants include a rare earth and/or a heavy metal and/or compounds of these elements. More preferably, the rare earth is Erbium or Neodymium.

Preferably, the refractive indices of the first core layer and the second core layer are substantially equal.

Preferably, the refractive index of the waveguide core differs from that of the substrate by at least 0.05%.

Preferably, the thickness of the first core layer is in the range 0.2 μm to 30 μm.

Preferably, the thickness of the second core layer is in the range 0.2 μm to 30 μm.

Preferably, the width of the waveguide core lies in the range 0.4 μm to 60 μm.

The upper cladding layer and the lower cladding layer may comprise the same material. The refractive index of the substrate and the refractive index of the upper cladding layer may be substantially equal.

In accordance with a second aspect of the invention there is provided a method of fabricating a waveguide comprising the steps of: providing a substrate; forming a waveguide core on the substrate; and forming an upper cladding layer to embed the waveguide core, wherein the waveguide core is formed from a first core layer and a second core layer.

The formation of the substrate may include the formation of an intermediate layer formed on said substrate. The formation of the intermediate layer may include the formation of a buffer layer. The buffer layer may be formed by thermally oxidising the substrate.

The formation of the intermediate layer may further include the formation of a lower cladding layer formed on said buffer layer. The formation of the lower cladding layer may include doping said lower cladding layer with a dopant. The dopant may include dopant ions.

Preferably, the second core layer is formed on the first core layer and the first core layer is formed on the substrate. Alternatively, the first core layer may be formed on the second core layer and said second core layer may be formed on the substrate.

A further first core layer may be formed on the second core layer such that the first core layer sandwiches the second core layer.

The steps of forming any one of the substrate, first core layer, the second core layer, and the upper cladding layer may comprise the steps of:

depositing each layer; and

at least partially consolidating each layer.

Preferably, any one of the substrate, the first core layer, the second core layer and the upper cladding layer partially consolidated after deposition is fully consolidated with the full consolidation of any other of the first core layer, the second core layer or the upper cladding layer.

Preferably, the formation of the first core layer includes the doping of the first core layer with a dopant.

Preferably, the first core layer dopant permits the first core layer to exhibit a photosensitive response.

Preferably, the formation of the second core layer includes the doping of the second core layer with a dopant.

Preferably, the second core layer dopant induces amplification of an optical signal transmitted through

said waveguide core.

The formation of the substrate may include the doping of the substrate with a dopant. The dopant may include dopant ions.

Preferably, the substrate dopant includes a mobile dopant.

Preferably, said first core layer dopant ions include tin and/or cerium and/or sodium.

Preferably, said second core layer dopant ions include a rare earth and/or a heavy metal and/or compounds thereof.

Preferably, said rare earth is Erbium and/or Neodymium.

Preferably, the concentration of the first core layer dopant is selectively controlled during the formation of the first core layer and the concentration of the second core layer dopant is selectively controlled during the formation of the second core layer so that the refractive index of the first core layer and the refractive index of the second core layer are substantially equal.

Preferably, the concentrations of the first core layer dopant and second core layer dopant are controlled to give a refractive index for the waveguide core which differs from that of the substrate layer by at least 0.05%.

The lower cladding layer and said buffer layer may be formed substantially in the same step. At least one of the substrate, the first core layer, the second core

layer, and the upper cladding layer may be deposited by a Flame Hydrolysis Deposition process and/or Chemical Vapour Deposition process. The Chemical Vapour Deposition process may be a Low Pressure Chemical Vapour Deposition process or a Plasma Enhanced Chemical Vapour Deposition process.

Preferably, the consolidation is by fusing using a Flame Hydrolysis Deposition burner. Alternatively, the consolidation may be by fusing in a furnace.

The step of fusing the lower cladding layer and the step of fusing the first core layer and/or the second core layer may be performed simultaneously. The waveguide core may be formed from the first core layer and the second core layer using a dry etching technique and/or a photolithographic technique and/or a mechanical sawing process. The dry etching technique may comprise a reactive ion etching process and/or a plasma etching process and/or an ion milling process.

The waveguide core formed from the first core layer and the second core layer may be square or rectangular in cross-section.

In accordance with a third aspect of the invention there is provided a laser waveguide with multiple core layers comprising a waveguide according to the first aspect of the invention, the laser waveguide further comprising:

at least one grating formed in said waveguide core.

Preferably, the laser waveguide further comprises at least one optical interference mirror.

More preferably, the optical interference mirror is provided at the input of the waveguide. The interference mirror may be butt-coupled to or directly deposited at the input of the waveguide.

The laser waveguide may include two mirrors and a grating. Alternatively, the laser waveguide may include one mirror and two gratings. Alternatively, the laser waveguide may include three gratings. The grating formed may be a Bragg grating. The grating may form an output coupler for said laser waveguide.

The laser waveguide may further comprise an optical interference mirror butt coupled to or directly deposited at the output of the waveguide.

In accordance with a fourth aspect of the invention there is provided method of fabricating a laser waveguide, comprising forming a waveguide according to the method of the second aspect of the invention, the method of fabricating the laser waveguide further including the steps of:

forming at least one grating in said waveguide core.

The method may further include the step of attaching at least one optical interference mirror to the waveguide.

The optical interference mirror may be attached to an input of the waveguide.

The grating may be formed using a laser operating at a wavelength in the range of 150 nm to 400 nm through a phase mask deposited on top of said upper cladding layer of the waveguide. The mask may be a quartz mask. The grating may be formed using a using an interference

side writing technique. The grating may be formed using a direct writing technique. The grating formed may be a Bragg grating.

Preferably, in the above method, the optical interference mirror is butt-coupled to or directly deposited at the input of the waveguide.

The method may further comprise the step of attaching a second optical interference mirror to the output of the waveguide.

DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figs. 1A to 1C are schematic cross-sectional diagrams of a waveguide with multiple core layers during various stages of fabrication.

Fig. 2A is a schematic representation of a laser waveguide formed from the waveguide shown in Figs. 1A to 1C; and

Fig. 2B is a detail, to an enlarged scale, of the structure shown in Fig. 2A.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, Figs. 1A to 1C illustrate schematically stages in the fabrication of a waveguide with a multi-layered core according to the invention.

Referring now to Fig. 1A, there is illustrated a waveguide 1 which is fabricated from a substrate 2. The substrate 2 comprises a silicon wafer. However, other suitable substrates including silica and sapphire, may be used.

A silica buffer layer 3, comprising a thermally oxidised layer of the substrate 2, is formed on the substrate 2. The thickness of the buffer layer 3 is 15 μm which lies in a preferred range of 5 μm to 20 μm.

A suitable method, for example, a flame hydrolysis deposition (FHD) method, is used to deposit a first core layer 4 on top of the buffer layer 3. The thickness of the first core layer 4 is 2 μm which lies in a preferred range of 0.2 μm to 30 μm.

The material included in the first core layer 4 provides a high photosensitive response to an optical signal. In a preferred embodiment, the first core layer 4 includes a high concentration of Germanium dopant, for example 17 %wt, co-doped with Boron, for example 5 %wt. Other dopant ions can be included, or a mixture of dopant ions, for example, tin, cerium, and/or sodium.

The dopant and co-dopants are introduced during the deposition of the first core layer 4. The Germanium dopant induces a high photosensitive response and the Boron co-dopant lowers the refractive index induced by the high level of Germanium in the first core layer 4. The concentrations of the dopant and co-dopant are adjusted to 17% wt and 5% wt to give a difference between the refractive index of the first core layer 4 and the refractive index of the buffer layer 3 of 0.75% which lies in a preferred range of 0.05% to 2.0% .

The first core layer 4 is then consolidated by a suitable method, for example by a second pass of the FHD burner or by consolidating the waveguide 1 in an electrical furnace.

Fig. 1B shows a further stage in the fabrication of the waveguide 1 in which a second core layer 5 is formed on the first core layer 4.

The second core layer 5 is deposited on the first core layer 4 using a suitable method, for example FHD, and is then suitably consolidated, for example, in an electrical furnace.

The second core layer 5 is doped with rare earth dopant ions, for example Er^{+3}, using an aerosol doping technique, and co-doped, for example, with Phosphorus during the deposition of the second core layer 5. The thickness of the second core layer 5 is 4μm, which lies in the range of 0.2μm to 30μm.

Alternative methods can be used to dope the second core layer 5 such as solution doping. Preferably, the dopant and co-dopant are simultaneously introduced in a controlled manner during the deposition of the second core layer 5. The concentrations of the dopant and co-dopant can be controlled so that the second core layer 5 provides the desired signal gain for optical signals propagating through the waveguide and also to ensure that the refractive index of the second core layer 5 is matched to the refractive index of the first core layer 4. In this embodiment, the indices are substantially matched. Alternatively, the first core layer 4 and the second core layer 5 can be subjected to a further process, for example, UV trimming, to effect matching of their refractive indices.

The photosensitive response of the first core layer 4 in combination with the optical signal gain of the second core layer 5 effect the overall level of optical signal amplification provided by the waveguide 1.

A waveguide core 6 is then formed from the first core layer 4 and the second core layer 5 by using a suitable method, for example conventional photolithographic and/or reactive ion etching (RIE) methods. A portion of the second core layer 5 is suitably masked and the unwanted portions of the second core layer 5 and the underlying first core layer 4 are etched away to leave the waveguide core 6. The overall dimensions of the waveguide core 6 formed are 6μm x 6μm which is in a preferred range of 0.4μm x 0.4μm to 60 μm x 60μm.

The co-dopant, here Boron, in the first core layer 4 reduce the refractive index of the waveguide core 6 and enable single mode operation even for large waveguide cores, for example waveguide cores whose dimensions are in the range of 0.4μm x 0.4μm to 60 μm x 60μm. The co-dopant in the first core layer 4 can also provide other advantages such as enabling higher refractive index changes to occur during later stages of fabrication of a waveguide with multiple core layers.

The first core layer 4 effectively can reduce the optical signal gain provided by the second core layer 5. It is thus advantageous for the first core layer 4 to be as photosensitive as possible in particular as the refractive index modulation no longer occurs over the entire volume of the waveguide core 6.

Fig. 1C shows a further stage in the fabrication of the waveguide. An upper cladding layer 7 is deposited on the waveguide core 6 using an FHD method. The upper

cladding layer 7 embeds the waveguide core 6. The upper cladding layer 7 is doped during deposition, for example with Phosphorus and Boron, to adjust its refractive index until the refractive index of the upper cladding layer 7 matches the refractive index of the buffer layer 3. The upper cladding layer 7 is then consolidated, for example in an electrical furnace.

In a second preferred embodiment of the invention, a lower cladding layer is formed on top of the buffer layer 3 before the first core layer 4 is deposited and in which the level of dopant in the upper cladding layer 7 is adjusted until the refractive index of the upper cladding layer 7 matches that of the lower cladding layer. The lower cladding layer can be deposited and consolidated using the same techniques as the upper cladding layer 7.

In an alternative layer structure the first core layer 4 may be deposited on top of the second core layer 5 or respective first core layers 4 may be provided both below and on top of the second core layer 5. The core layer 5 is then sandwiched between two photo-sensitive first core layers 4 increasing the coupling coefficient of the device.

It is possible also, for certain applications, to dope the photo-sensitive first core layer 4 with a small amount of rare earth ions.

Referring now to Figs. 2A and 2B of the drawings, there is shown a schematic diagram of laser waveguide according to the invention. Figs. 2A and 2B show a cross-section parallel to the longitudinal axis of the laser waveguide core, such that the waveguide core is seen only in profile.

Fig. 2A shows a planar laser waveguide 10 incorporating a Bragg grating 11. The laser waveguide 10 includes a silicon substrate layer 12 and a silica buffer layer 13 comprising a thermally oxidised layer of the substrate 12. The buffer layer 13 is formed on the substrate layer 12.

Fig. 2B is an enlarged view of a section of Fig. 2A. A first core layer 14 is deposited and consolidated on the buffer layer 13 and second core layer 15 is deposited and consolidated on the first core layer 14 using the techniques described above for the deposition and consolidation of first and second core layers 4 and 5 in the waveguide 1. The first core layer 14 can alternatively be formed on an lower cladding layer (not shown) formed on buffer layer 13.

The second core layer 15 is doped with neodymium instead of the erbium used as a dopant in the second core layer 5. Fig. 2A represents a cross-section through the laser waveguide 10 parallel to the direction of light propagation through the waveguide 10 (i.e., normal to the cross-sectional plane through the waveguide shown in Fig. 1C). The waveguide core 16 is formed from said first core layer 14 and said second core layer 15 using the same technique described above for the formation of the first core layer 4 and the second core layer 15.

An upper cladding layer 17 is then deposited on the second core layer 15 and the grating 11. The upper cladding layer 17 is deposited and consolidated using the same methods as described above for the deposition and consolidation of the upper cladding layer 7 in the fabrication of waveguide 1.

The laser cavity of the laser waveguide 10 is fabricated by writing the Bragg grating 11 into a generally central portion of the first core layer 14 and the second core layer 15. Conventionally, the Bragg grating 11 may be written using a KrF excimer laser operating at 248 nm through a quartz phase mask deposited on top of the upper cladding layer.

An input 18 of the laser waveguide 10 provides an optical signal at a pump wavelength to the laser waveguide 10. An optical interference mirror 19 butt-coupled to the input end 18 of the laser waveguide 10 has a high reflectivity (R_{sig} = 99.9%) around the maxima of the desired output wavelength and has a high transmittance at the pump wavelength (T_{pump} > 95%). The grating 11 forms an output coupler at the output 20 of the laser waveguide 10.

The grating 11 is designed for use at 1050 nm and the reflectivity of the grating 11 formed saturates at 80%. The phase mask used to form the grating 11 has a pitch of 720 nm. In other embodiments, however, it is possible to form gratings 11 which can be used at a wavelength in the range of 500 nm to 2100 nm by using suitable phase masks.

In another embodiment of a laser waveguide, a grating 11 can be provided at both the input 18 and the output 20 of the laser waveguide 10, preferably with both gratings having substantially the same Bragg wavelength thus providing a distributed Bragg reflection laser (DBR).

In yet another embodiment, a distributed feedback laser (DFB) can also be formed by having a grating extending

along the length of the gain cavity formed by the core layer 5.

Further, a multicavity laser can be formed by butt-coupling another mirror to the output end of the laser waveguide 10. These external mirrors can be bulk mirror butt-coupled or mirrors directly deposited on the ends of the waveguide. A multiple wavelength laser can be provided by photoimprinting a sampled grating in the waveguide core, with precise control of channel spacing. Additionally, a multiple wavelength laser can be achieved by exposing the same core area to very similar UV patterns, with each exposure determining each one of the emission wavelengths of the superimposed Bragg gratings. An additional grating can be defined to provide gain equalisation for the several wavelengths.

Thus, a multicavity laser can be constructed by using two mirrors and a grating, one mirror and two gratings, or indeed three gratings.

Still further, in a different application, for example, optical amplifiers, a grating can also be formed on the first core layer 4 to act as a "tap" to flatten optical gain spectra.

While several embodiments of the present invention have been described and illustrated, it will be apparent to those skilled in the art once given this disclosure that various modifications, changes, improvements and variations may be made without departing from the spirit or scope of this invention.

ART 34 AMDT

Claims

1. An optical waveguide with multiple core layers for transmitting an optical signal, the waveguide including:
a substrate;
a waveguide core formed on the substrate and comprising a first core layer and a second core layer;
an upper cladding layer embedding said waveguide core;
wherein the first core layer includes a dopant to permit the first core layer to exhibit a photosensitive response, and the second core layer includes a dopant to induce amplification of an optical signal transmitted through said waveguide core.

2. An optical waveguide according to Claim 1, wherein the first core layer includes a germanium oxide to permit the first core layer to exhibit a photosensitive response.

3. An optical waveguide according to Claim 2, wherein the first core layer further includes a boron oxide.

4. A waveguide as claimed in any preceding claim, wherein the substrate comprises silicon and/or silica and/or sapphire.

5. A waveguide as claimed in any preceding claim, wherein the substrate includes an intermediate layer.

6. A waveguide as claimed in Claim 5, wherein the intermediate layer includes a buffer layer formed on the substrate.

7. A waveguide as claimed in Claim 6, wherein said buffer layer comprises a thermally oxidised layer of the substrate.

8. A waveguide as claimed in Claim 6 or Claim 7, wherein the intermediate layer further includes a lower cladding layer formed on said buffer layer.

9. A waveguide as claimed in any of Claims 6 to 8, wherein the thickness of the buffer layer is in the range 5 m to 20 m.

10. A waveguide as claimed in any preceding claim, wherein the second core layer is formed on the first core layer and said first core layer is formed on the substrate.

11. A waveguide as claimed in any of Claims 1 to 9, wherein the first core layer is formed on the second core layer and said second core layer is formed on the substrate.

12. A waveguide as claimed in Claim 10, wherein a further first core layer is formed on the second core layer such that the first core layer sandwiches the second core layer.

13. A waveguide as claimed in any preceding claim, wherein the first core layer includes silica.

14. A waveguide as claimed in any preceding claim, wherein the first core layer dopant includes dopant ions.

15. A waveguide as claimed in Claim 14, wherein the first core layer dopant ions include tin and/or cerium and/or sodium.

16. A waveguide as claimed in any preceding claim, wherein the second core layer includes silica.

17. A waveguide as claimed in any preceding claim, wherein the second core layer includes a phosphorus oxide.

18. A waveguide as claimed in any preceding claim, wherein the second core layer dopant includes dopant ions.

19. A waveguide as claimed in Claim 18, wherein the second core layer dopant includes a mobile dopant.

20. A waveguide as claimed in any of Claims 16 to 19, wherein the second core layer dopant includes a rare earth and/or a heavy metal and/or compounds of these elements.

21. A waveguide as claimed in Claim 20, wherein the rare earth is Erbium or Neodymium.

22. A waveguide as claimed in any preceding claim, wherein the refractive indices of the first core layer and the second core layer are substantially equal.

23. A waveguide as claimed in any preceding claim, wherein the refractive index of the waveguide core differs from that of the substrate by at least 0.05%.

24. A waveguide as claimed in any preceding claim, wherein the thickness of the first core layer is in the range 0.2 m to 30 m.

25. A waveguide as claimed in any preceding claim, wherein the thickness of the second core layer is in the range 0.2 m to 30 m.

26. A waveguide as claimed in Claim 24, wherein the width of the waveguide core lies in the range 0.4 m to 60 m.

27. A waveguide as claimed in any of Claims 8 to 26, wherein the upper cladding layer and the lower cladding layer comprise the same material.

28. A waveguide as claimed in any preceding claim, wherein the refractive index of the substrate and the refractive index of the upper cladding layer are substantially equal.

29. An optical waveguide according to any of Claims 1 to 28, wherein the first core layer includes at least 17% wt germanium dopant.

30. A method of fabricating a waveguide comprising the steps of:

providing a substrate;

forming a waveguide core on the substrate, the waveguide core comprising a first core layer and a second core layer;

forming an upper cladding layer to embed the waveguide core;

wherein the formation of the first core layer includes the doping of the first core layer with a dopant for permitting the first core layer to exhibit a photosensitive response, and the formation of the second core layer includes the doping of the second core layer with a dopant for inducing amplification of an optical signal transmitted through said waveguide core.

31. A method according to Claim 30, wherein the dopant used to permit the first core layer to exhibit a photosensitive response is a germanium dopant.

32. A method according to Claim 31, wherein the first core layer is co-doped with a boron dopant.

33. A method as claimed in any of Claims 30 to 32, wherein the formation of the substrate includes the formation of an intermediate layer formed on said substrate.

34. A method as claimed in Claim 33, wherein the formation of the intermediate layer includes the formation of a buffer layer.

35. A method as claimed in Claim 34, wherein the buffer layer is formed by thermally oxidising the substrate.

36. A method as claimed in Claim 34 or Claim 35, wherein the formation of the intermediate layer further includes the formation of a lower cladding layer formed on said buffer layer.

37. A method as claimed in Claim 36, wherein the formation of the lower cladding layer includes doping said lower cladding layer with a dopant.

38. A method as claimed in Claim 37, wherein the dopant includes dopant ions.

39. A method as claimed in any of Claims 30 to 38, wherein the second core layer is formed on the first core layer and wherein the first core layer is formed on the substrate.

40. A method as claimed in any of Claims 30 to 39, wherein the first core layer is formed on the second core layer and said second core layer is formed on the substrate.

41. A method as claimed in Claim 39, wherein a further first core layer is formed on the second core layer such that the first core layer sandwiches the second core layer.

42. A method as claimed in any of Claims 30 to 41, wherein the steps of forming any one of the substrate, first core layer, the second core layer, and the upper cladding layer comprise the steps of:
depositing each layer; and
at least partially consolidating each layer.

43. A method as claimed in Claim 42, wherein any one of the substrate, the first core layer, the second core layer and the upper cladding layer partially consolidated after deposition is fully consolidated with the full consolidation of any other of the first core layer, the second core layer or the upper cladding layer.

44. A method as claimed in any of Claims 30 to 43, wherein the formation of the substrate includes the doping of the substrate with a dopant.

45. A method as claimed in any of Claims 30 to 44, wherein the dopant includes dopant ions.

46. A method as claimed in Claim 44 or Claim 45, wherein the substrate dopant includes a mobile dopant.

47. A method as claimed in Claim 45 or Claim 46, wherein said first core layer dopant ions include tin and/or cerium and/or sodium.

48. A method as claimed in any of Claims 45 to 47, wherein said second core layer dopant ions include a rare earth and/or a heavy metal and/or compounds thereof.

49. A method as claimed in Claim 48, wherein said rare earth is Erbium and/or Neodymium.

50. A method as claimed in any of Claims 30 to 49, wherein the concentration of the first core layer dopant is selectively controlled during the formation of the

first core layer and the concentration of the second core layer dopant is selectively controlled during the formation of the second core layer so that the refractive index of the first core layer and the refractive index of the second core layer are substantially equal.

51. A method as claimed in Claim 50, wherein the concentrations of the first core layer dopant and second core layer dopant are controlled to give a refractive index for the waveguide core which differs from that of the substrate layer by at least 0.05%.

52. A method as claimed in any of Claims 34 to 51, wherein said lower cladding layer and said buffer layer are formed substantially in the same step.

53. A method as claimed in any of Claims 42 to 52, wherein at least one of the substrate, the first core layer, the second core layer, and the upper cladding layer is deposited by a Flame Hydrolysis Deposition process and/or Chemical Vapour Deposition process.

54. A method as claimed in Claim 53, wherein the Chemical Vapour Deposition process is a Low Pressure Chemical Vapour Deposition process or a Plasma Enhanced Chemical Vapour Deposition process.

55. A method as claimed in any of Claims 42 to 54, wherein the consolidation is by fusing using a Flame Hydrolysis Deposition burner.

56. A method as claimed in any of Claims 42 to 55, wherein the consolidation is by fusing in a furnace.

57. A method as claimed in Claim 55 or Claim 56, wherein the step of fusing the lower cladding layer and the step of fusing the first core layer and/or the second core layer are performed simultaneously.

58. A method as claimed in any of Claims 30 to 57, wherein the waveguide core is formed from the first core layer and the second core layer using a dry etching technique and/or a photolithographic technique and/or a mechanical sawing process.

59. A method as claimed in Claim 58, wherein the dry etching technique comprises a reactive ion etching process and/or a plasma etching process and/or an ion milling process.

60. A method as claimed in any of Claims 30 to 59, wherein the waveguide core formed from the first core layer and the second core layer is square or rectangular in cross-section.

61. A method according to any of Claims 30 to 60, wherein the first core layer is doped with at least 17%wt germanium dopant.

62. A laser waveguide with multiple core layers for transmitting an optical signal, the laser waveguide comprising a waveguide as claimed in any of claims 1 to 29, the laser waveguide further comprising:

at least one grating formed in said waveguide core.

63. A laser waveguide as claimed in Claim 62, wherein the laser waveguide further comprises at least one optical interference mirror.

64. A laser waveguide as claimed in Claim 63, wherein the optical interference mirror is provided at the input of the waveguide.

65. A laser waveguide as claimed in Claim 64, wherein the interference mirror is butt-coupled to or directly deposited at the input of the waveguide.

66. A laser waveguide as claimed in any of Claims 62 to 65, wherein the laser waveguide includes two mirrors and a grating.

67. A laser waveguide as claimed in any of Claims 62 to 65, wherein the laser waveguide includes one mirror and two gratings.

68. A laser waveguide as claimed in Claim 62, wherein the laser waveguide includes three gratings.

69. A laser waveguide as claimed in any of Claims 62 to 68, wherein the grating formed is a Bragg grating.

70. A laser waveguide as claimed in any of Claims 62 to 69, wherein said grating forms an output coupler for said laser waveguide.

71. A laser waveguide as claimed in any of Claims 62 to 70 further comprising an optical interference mirror butt coupled to or directly deposited at the output of the waveguide.

72. A method of fabricating a laser waveguide, comprising forming a waveguide according to a method as claimed in any of Claims 30 to 61, the method of fabricating the laser waveguide further including the steps of: forming at least one grating in said waveguide core.

73. A method as claimed in Claim 72, further including the step of attaching at least one optical interference mirror to the waveguide.

74. A method as claimed in Claim 73, wherein the optical interference mirror is attached to an input of the waveguide.

75. A method as claimed in any of Claims 72 to 74, wherein the grating is formed using a laser operating at a wavelength in the range of 150 nm to 400 nm through a phase mask deposited on top of said upper cladding layer of the waveguide.

76. A method as claimed in Claim 75, wherein said mask is a quartz mask.

77. A method as claimed in any of Claims 72 to 74, wherein the grating is formed using a using an interference side writing technique.

78. A method as claimed in any of Claims 72 to 74, wherein the grating is formed using a direct writing technique.

79. A method as claimed in any of Claims 72 to 78, wherein the grating formed is a Bragg grating.

80. A method as claimed in any of Claims 73 to 79, wherein the optical interference mirror is butt-coupled to or directly deposited at the input of the waveguide.

81. A method as claimed in any of Claims 72 to 79, further comprising the step of attaching a second optical interference mirror to the output of the waveguide.

82. A waveguide substantially as described herein and with reference to Figs. 1A to 1C of the accompanying drawings.

83. A laser waveguide substantially as described herein and with reference to Figs. 2A and 2B of the accompanying drawings.

84. A method of fabricating a waveguide with multiple core layers substantially as described herein and with reference to Figs. 1A to 1C of the accompanying drawings.

85. A method of fabricating a laser waveguide with multiple core layers substantially as described herein and with reference to Figs. 2A and 2B of the accompanying drawings.

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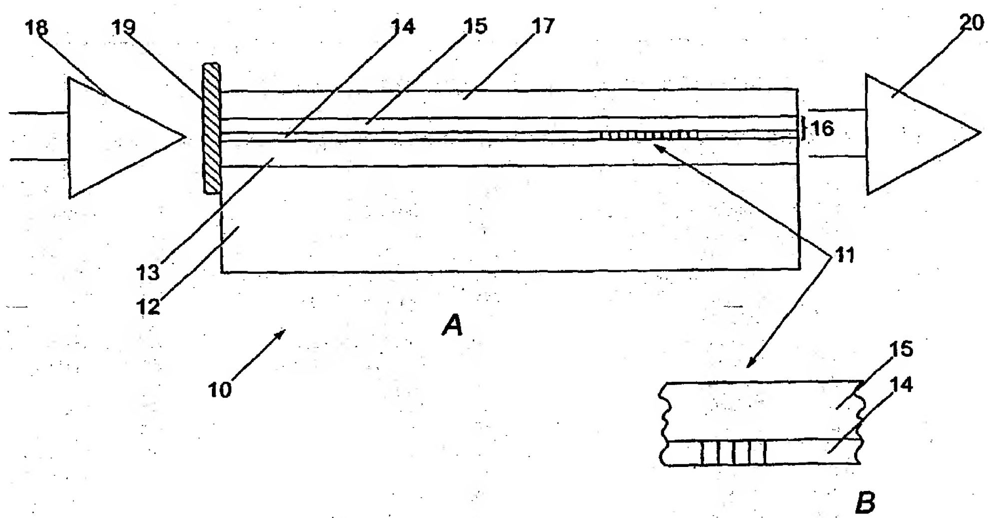

(57) Abstract

An optical waveguide with multiple core layers for transmitting an optical signal comprises a substrate; an intermediate layer formed on said substrate; a waveguide core formed on said intermediate layer; and an upper cladding layer embedding said waveguide core. The waveguide core comprises a first core layer formed on said intermediate layer and a second core layer formed on said first core layer. The first core layer has photosensitive properties and the second core layer has optical gain properties.

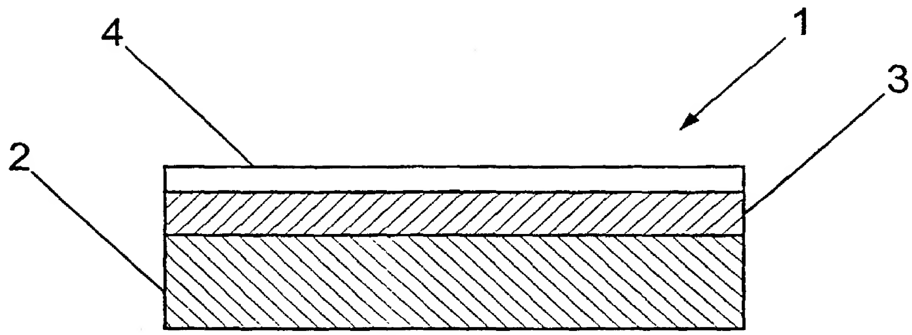

Fig. 1A

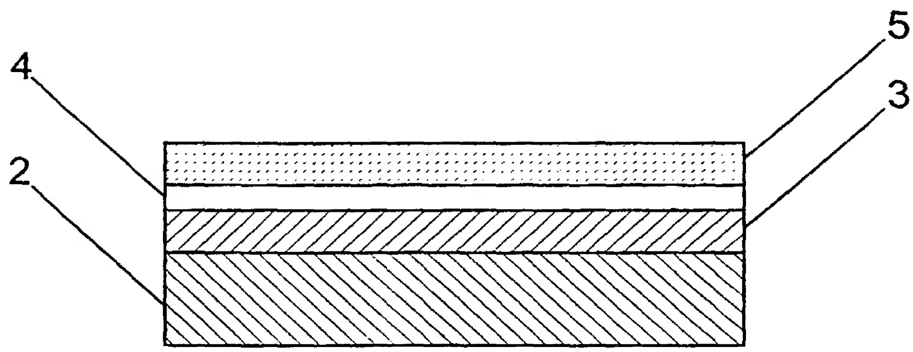

Fig. 1B

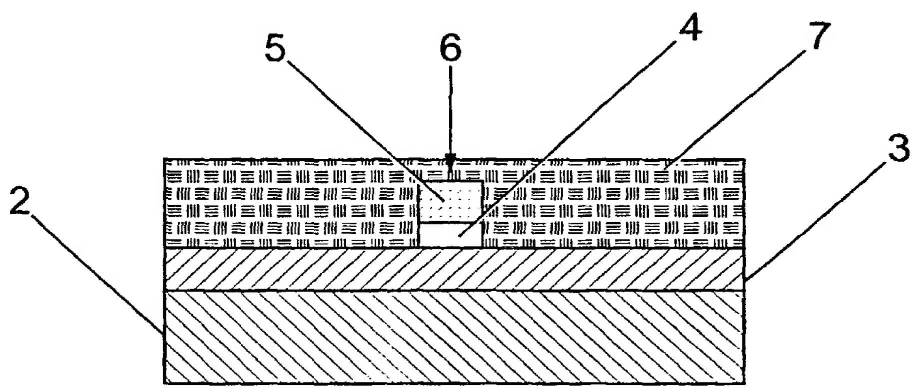

Fig. 1C

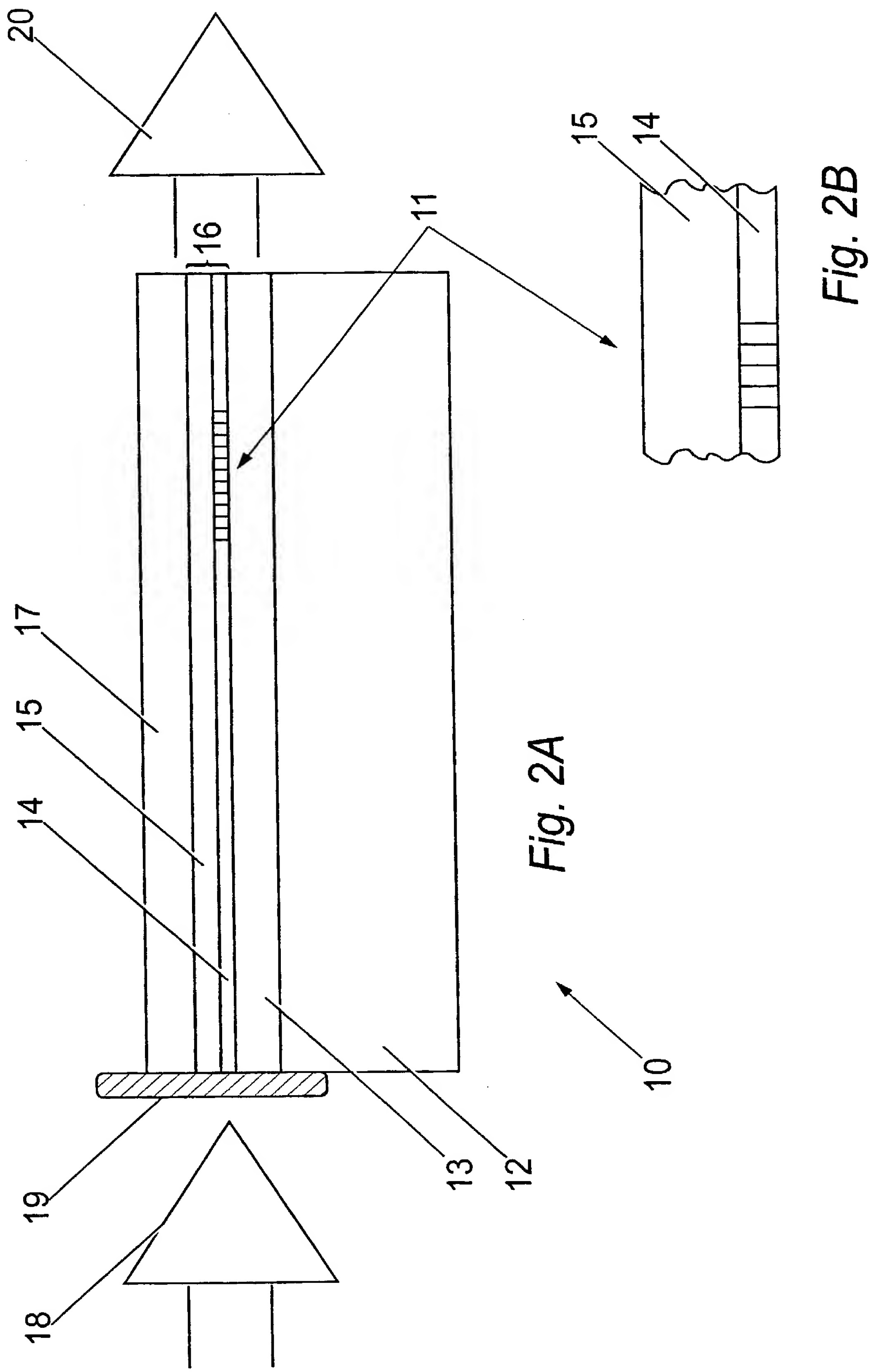

Fig. 2A

Fig. 2B

Atty Docket No.: **MCW-002US**

DECLARATION, PETITION AND POWER OF ATTORNEY FOR PATENT APPLICATION

(Check one):

☐ Declaration Submitted with Initial Filing

☒ Declaration Submitted after Initial Filing

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

OPTICAL WAVEGUIDE WITH MULTIPLE CORE LAYERS AND METHOD OF FABRICATION THEREOF

the specification of which (check one):

☐ is attached hereto.

OR

☒ was filed on **07 February 2000** as PCT International Application Number **PCT/GB00/00323** and as **U.S. Serial No. 09/890,694.**

☐ and was amended by PCT Article 19 Amendment on ____________ (if applicable).

☐ and was amended by PCT Article 34 Amendment on ____________ (if applicable).

I acknowledge the duty to disclose to the Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

I hereby state that I have reviewed and understood the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

PRIORITY CLAIM

(Check one):

☐ no such applications have been filed.

☒ such applications have been filed as follows

1) **FOREIGN PRIORITY CLAIM:** I hereby claim foreign priority benefits under Title 35, United States Code, §119(a)-(d) or §365(b) of any foreign application(s) for patent or inventor's certificate or §365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (dd/mm/yyyy)	Priority Not Claimed	Certified Copy Attached	
				Yes	No
9902477.0	GB	05 February 1999 (05.02.1999)	☐	☐	☒
			☐	☐	☐

☐ Additional foreign application numbers are listed on a supplemental priority sheet attached hereto.

2) **PROVISIONAL PRIORITY CLAIM:** I hereby claim the benefit under Title 35, United States Code §119(e) of any United States provisional application(s) listed below.

Provisional Application Number(s)	Filing Date (dd/mm/yyyy)

☐ Additional provisional application numbers are listed on a supplemental priority sheet attached hereto.

3) **U.S./PCT PRIORITY CLAIM:** I hereby claim the benefit under Title 35, United States Code, §120 of any United States application or §365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT international application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application Number	PCT Parent Number	Parent Filing Date (dd/mm/yyyy)	Parent Patent Number *(if applicable)*

☐ Additional U.S. or PCT international application numbers are listed on a supplemental priority sheet attached hereto.

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POWER OF ATTORNEY:

As a named inventor, I hereby appoint the following attorneys and/or agents to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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Wherefore I petition that letters patent be granted to me for the invention or discovery described and claimed in the attached specification and claims, and hereby subscribe my name to said specification and claims and to the foregoing declaration, power of attorney, and this petition.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

1-00

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4-00

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